EUROPEAN UNIVERSITY INSTITUTE, FLORENCE
DEPARTMENT OF ECONOMICS

E U I W O R K I N G P A P E R No.85/188

SCATTERED SELLERS AND ILL-INFORMED BUYERS: A MODEL OF PRICE DISPERSION

BY

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This paper was written while the first author was visiting the European University Institute, Florence. Financial support is gratefully acknowledged.
The authors are grateful to C. Blackorby and A. Kirman for helpful comments.

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Printed in Italy in September 1985
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Abstract

In this paper we study a model where two spatially scattered sellers face a population of consumers dispersed over a given geographical area; they have to incur a transaction cost to place their purchase order . Moreover these consumers have imperfect knowledge of prices, but obtain full information about prices at the first shop they solicit. We study price competition between these firms. The main outcomes of our analysis are as follows. First we show that whenever a price equilibrium exists for given locations of firms, it will necessarily display price dispersion. Second we study location configurations which ensure the existence of a price equilibrium. Furthermore we show that when it exists, a price equilibrium is unique. Finally we analyze firms revenues when merchants anticipate the consequences of their locational choice on subsequent price competition. Then we find that there is an incentive for a firm to get as close as possible to its competitor.

SCATTERED SELLERS AND ILL-INFORMED BUYERS :

A MODEL OF PRICE DISPERSION

Jean J. Gabszewicz and Paolo Garella

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In this paper we study a model where two spatially scattered merchants selling a homogeneous product, face a population of consumers dispersed over a given geographical area. If a firm receives a purchase order from a particular consumer, it delivers the product at home at no cost. However consumers have to incur a transaction cost to place their purchase order, proportional to the distance between their location and the firm (a possible interpretation of this transaction cost is the price of phoning or telexing the firm which has been chosen for purchase).

We also assume that consumers face imperfect knowledge of prices : while they know the distribution of prices, they cannot a priori identify which seller quotes which price. In order to identify prices at each shop consumers have to contact the firms. At his first search a consumer is then faced with the following alternative : either to buy immediately from the seller solicited at the observed price, or place the purchase order at the other shop while thereof covering the cost required by the second phone call and the price set at this other shop. Therefore, the firm which is first solicited by a particular consumer provides this consumer with a specific advantage over the other : he collects there full information about prices in both shops while he can simultaneously place his purchase order. As a consequence of this asymmetry, the order in which shops are solicited matters. When a consumer will choose to solicit first a particular seller rather than the other ? We assume that the probability of observing a particular price is equal at each shop; then, a consumer first solicits the shop which is closest to him since this choice minimizes expected search costs. Therefore each seller according to his location enjoys a "natural" market : all consumers who are closer to him than his competitor first canvass his own shop. He can hope to keep those customers in his shop even by quoting a price somewhat higher than the price set by his competitor. The same consumers inertia is also observed at the other firm relative to its own "natural" market. How does price competition operate in such an environment is the question addressed in this paper.

In the present study we have chosen to approach this question in a model of duopolistic competition which borrows both from location theory, developed after Hotelling (1929), and from equilibrium models of price search, developed after Stigler (1961) (For location models see, for instance : d'Aspremont, Gabszewicz and Thisse (1979), Eaton and Lipsey (1975), Economides (1981), Salop (1979) or Stahl (1983); as for equilibrium search models, see Burdett and Judd (1983), Carlson and McAfee (1983), Reinganum (1979) or Rotschild (1973)).

The main outcomes of our analysis are as follows. First we show that whenever a price equilibrium exists for given locations of firms, it will *necessarily* display price dispersion. Second we study location configurations which ensure the existence of a price equilibrium. Surprisingly enough, these configurations exclude the possibility that firms be too far apart from each other; then no price equilibrium would obtain. Furthermore we show that when it exists, a price equilibrium is unique. Finally we analyze firms revenues when merchants anticipate the consequences of their locational choice on subsequent price competition. Then we find that there is an incentive for a firm to get as close as possible to its competitor.

It is interesting to compare the present study to another work that the authors are completing in a companion paper (Gabszewicz, J. and P. Garella (1985)). The main problem considered here is treated there in a similar manner, with the sole exception that the information endowments of consumers about prices are represented by prior beliefs. The nature of the results is drastically affected by this change in the corpus of assumptions. This indicates that the hypothesis on information plays a central role on the nature of competition.

2. THE MODEL

To start out we consider a classical Hotelling location model. On a line of length L , two sellers 1 and 2 of a homogeneous product with zero production cost, are located at respective distances a and b from the ends of this line ($a + b \leqslant L$; $a \geqslant 0$, $b \geqslant 0$, $a \neq L - b$). Customers are evenly distributed along this line, and each customer consumes exactly a single unit of this commodity irrespective of its price. We depart from Hotelling by assuming that consumers while knowing the distribution of prices, cannot identify which seller quotes which price;

the probability of observing a particular price is assumed equal at each shop. Moreover we assume that customers may solicit (call) the shops at a cost increasing linearly with distance while firms deliver the product at home at no cost.

From those assumptions it is easily seen that a consumer will buy from the nearest seller if, and only if, he finds out that the price in this shop is smaller than the price at the other one, plus the cost of soliciting this other shop. Formally letting t denote a particular customer on the line $[0,L]$, all customers t in the interval $A_1 \underset{\text{Def}}{=} \left[0, \frac{L+a-b}{2}\right[\left(\text{resp. } A_2 = \left[\frac{L+a-b}{2}, L\right]\right)$ first call seller 1 (resp. 2) (see figure 1) ,

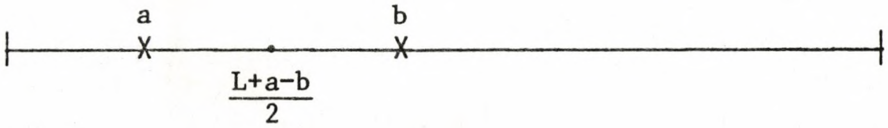


Figure 1.

Then the cost $c(t)$ of soliciting (eventually) the other shop amounts to

$$c(t) = c \cdot [(L-b) - t] , \qquad \text{if } 0 \leq t < \frac{L+a-b}{2} ,$$

and

$$c(t) = c \cdot (t-a) , \qquad \text{if } \frac{L+a-b}{2} \leq t \leq L ,$$

where the scalar c denotes the cost, per unit of distance, of canvassing a particular shop. Finally customer t in A_1 (resp. A_2) buys from shop 1 (resp. 2) if, and only if, $p_1 \leq p_2 + c(L-b-t)$ (resp. $p_2 \leq p_1 + c(t-a)$) where p_i denotes the price at shop i , $i = 1,2$.

Given (p_1, p_2), the set of customers first calling seller 1 *and* placing a purchase order there is equal to $\{t \mid p_1 \leq p_2 + c(L-b-t);\ t \in A_1\}$ and coincides with the interval A_{11} , with A_{11} defined by

$$A_{11} = \left[0, \operatorname{Min}\left\{\frac{L+a-b}{2}, \frac{p_2 - p_1 + c(L-b)}{c}\right\}\right] .$$

Similarly the set of customers first visiting seller 2 *and* buying from him is equal to $\{t \mid p_2 \leq p_1 + c(t-a);\ t \in A_2\}$, and coincides with the interval A_{22} where

$$A_{22} = \left[\operatorname{Max}\left\{\frac{L+a-b}{2}, \frac{p_2 - p_1 + ac}{c}\right\}, L\right] .$$

In a similar manner we can identify the interval of customers first visiting seller 1 (resp. 2), but preferring ex post to place their purchase order at seller 2 (resp. 1), i.e.

$$A_{12} = \left[\mathrm{Min} \left\{ \frac{L+a-b}{2} \; , \; \frac{p_2 - p_1 + c(L-b)}{c} \right\}, \; \frac{L+a-b}{2} \right] = A_1 \setminus A_{11}$$

$$\left(\text{resp.} \quad A_{21} = \left[\frac{L+a-b}{2} \; , \; \mathrm{Max} \left\{ \frac{L+a-b}{2} \; , \; \frac{p_2 - p_1 + ac}{c} \right\} \right] = A_2 \setminus A_{22} \right) .$$

Let us define $\bar{p}_1$ as the solution of the equation

$$\frac{L+a-b}{2} = \frac{p_2 - p_1 + ac}{c} ,$$

i.e., $\bar{p}_1 = p_2 - \frac{c(L-a-b)}{2}$: if seller 1 sets a price exceeding $\bar{p}_1$, given p_2, no customer who first visited firm 2, is still attracted by the offer of firm 1. Similarly define $\bar{\bar{p}}_1$ as the solution of the equation

$$\frac{L+a-b}{2} = \frac{p_2 - p_1 + c(L-b)}{c} ,$$

i.e. $\bar{\bar{p}}_1 = p_2 + \frac{c(L-a-b)}{2}$: if seller 1 sets a price exceeding $\bar{\bar{p}}_1$, given p_2, some customers who first visited firm 1 start to place orders at firm 2. Notice that $\bar{p}_1 < \bar{\bar{p}}_1$ if $a \neq L-b$, as it is assumed. Hence in the domain $[\bar{p}_1, \bar{\bar{p}}_2]$ demand addressed to firm 1 remains totally inelastic to p_1, and consists of all buyers in A_1, i.e. demand is equal to $\frac{L+a-b}{2}$. In an analogous way, we can define $\bar{p}_2 = p_1 - \frac{c(L-a-b)}{2}$ and $\bar{\bar{p}}_2 = p_1 + \frac{c(L-a-b)}{2}$, and demand addressed to firm 2 remains equal to $\frac{L+a-b}{2}$ in the domain $[\bar{p}_2, \bar{\bar{p}}_2]$. We are now in a position to derive the (contingent) demand functions to firm 1 and firm 2, respectively. We have

$$\begin{aligned}
D_1(p_1, p_2) &= \frac{p_2 - p_1 + ac}{c} , && \text{if } 0 \leq p_1 < p_2 - \frac{c(L-a-b)}{2} ; \\
&= \frac{L+a-b}{2} , && \text{if } p_2 - \frac{c(L-a-b)}{2} \leq p_1 \leq p_2 + \frac{c(L-a-b)}{2} ; \\
&= \frac{p_2 - p_1 + c(L-b)}{c} , && \text{if } p_2 + \frac{c(L-a-b)}{2} < p_1 \leq p_2 + c(L-b) ; \\
&= 0 , && \text{if } p_2 + c(L-b) < p_1 .
\end{aligned}$$

Figure 1 depicts the demand function to firm 1, for a given p_2.

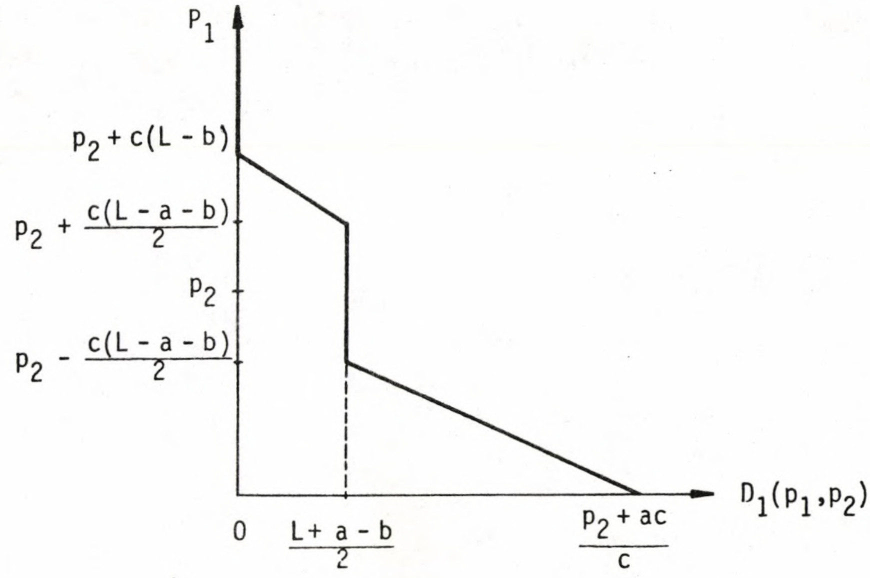


Figure 2.

Similarly, we get

$$
\begin{aligned}
D_2(p_1,p_2) &= L - \frac{p_2 - p_1 + c(L-b)}{c}, \text{ if } 0 \leqslant p_2 < p_1 - \frac{c(L-a-b)}{2} \quad ; \\
&= \frac{L-a+b}{2}, \text{ if } p_1 - \frac{c(L-a-b)}{2} \leqslant p_2 \leqslant p_1 + \frac{c(L-a-b)}{2} \; ; \\
&= L - \frac{p_2 - p_1 + ac}{c}, \text{ if } p_1 + \frac{c(L-a-b)}{2} < p_2 \leqslant p_1 + c(L-a); \\
&= 0, \qquad \text{if } p_1 + c(L-a) < p_2 \; .
\end{aligned}
$$

The revenue functions of the firms, corresponding to these contingent demand functions write as $R_1(p_1, p_2) = p_1 \, D_1(p_1, p_2)$ and $R_2(p_1, p_2) = p_2 \, D_2(p_1, p_2)$, respectively. Typically their graph consists of a linear segment connecting two quadratic pieces, as represented on Figure 3. A (Nash) *price equilibrium* is a pair (p_1^*, p_2^*) such that $R_1(p_1^*, p_2^*) \geqslant R_1(p_1,p_2^*)$, $\forall p_1$, and $R_2(p_1^*, p_2^*) \geqslant R_2(p_1^*, p_2)$, $\forall p_2$.

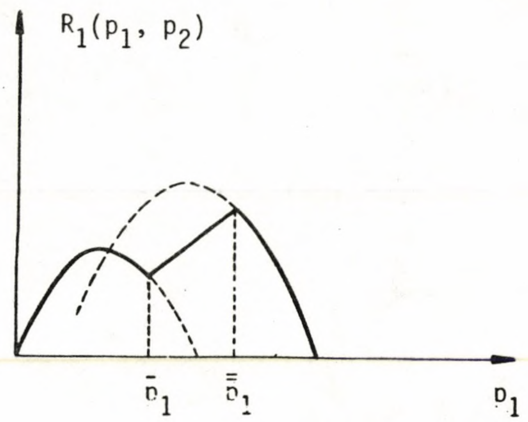


Figure 3.

By contrast with Hotelling's model, the demand and revenue functions of the firms are continuous. But the present model shares with the Hotelling's one the property that neither the demand, nor the revenue functions are concave[1].

3. THE EQUILIBRIUM ANALYSIS

In the following we perform an analysis of the various properties enjoyed by a price equilibrium for the situation depicted above. We start by showing that, if an equilibrium exists, prices must be dispersed at equilibrium.

PROPOSITION 1. (Price Dispersion)

If a price equilibrium (p_1^*, p_2^*) *exists, it is defined by* $p_1^* = \frac{c}{3}(L+a)$, $p_2^* = \frac{c(2L-a)}{3}$ *(equilibrium of type I), or by* $p_1^* = \frac{c}{3}(L+b)$, $p_2^* = \frac{c(2L-b)}{3}$ *(equilibrium of type II).*

Proof : The proof of the proposition proceeds by eliminating various domains of price pairs which are not admissible as price equilibria. Assume that (p_1^*, p_2^*) is a price equilibrium, and define the following price domains :

$$D_{11} = \left\{p_1 \mid p_2^* + c(L-b) \geqslant p_1 > p_2^* + \frac{c(L-a-b)}{2}\right\};$$

$$D_{12} = \left\{p_1 \mid p_2^* + \frac{c(L-a-b)}{2} \geqslant p_1 \geqslant p_2^* - \frac{c(L-a-b)}{2}\right\};$$

$$D_{13} = \left\{p_1 \mid p_2^* - \frac{c(L-a-b)}{2} > p_1 \geqslant 0\right\}.$$

In an analogous manner, define

$$D_{21} = \left\{p_2 \mid p_1^* + c(L-a) \geqslant p_2 > p_1^* + \frac{c(L-a-b)}{2}\right\};$$

$$D_{22} = \left\{p_2 \mid p_1^* + \frac{c(L-a-b)}{2} \geqslant p_2 \geqslant p_1^* - \frac{c(L-a-b)}{2}\right\};$$

$$D_{23} = \left\{p_2 \mid p_1^* - \frac{c(L-a-b)}{2} > p_2 \geqslant 0\right\}.$$

---

[1]Notice that throughout the whole analysis we exclude the possibility that both sellers are located at the same place $(a = L-b)$. In that case, for each customer there is no cost advantage to sample one seller before the other. Accordingly each seller should expect to be solicited and obtain half of the population of customers. However this sharing of the market is not consistent with our definitions of A_1 and A_2, so that our analysis cannot extend to the case $a = L-b$.

(The graphs of the demand functions $D_1(p_1, p_2^*)$ and $D_2(p_1^*, p_2)$, and the corresponding domains of prices are represented on Figure 4).

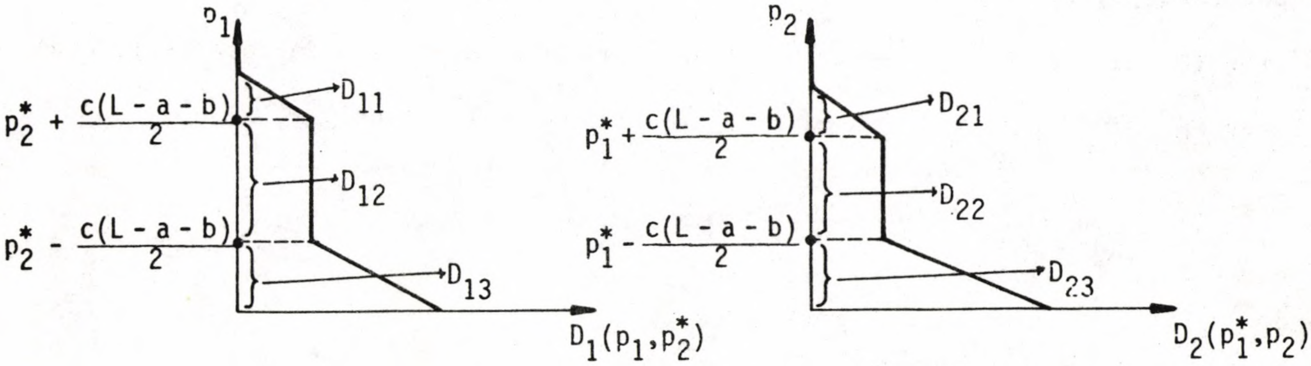


Figure 4.

First, no price equilibrium can obtain with $p_1^* \in D_{12}$ and $p_2^* \in D_{22}$. Indeed since demand is inelastic to price in the corresponding range for each firm, revenue maximization in D_{12} implies that $p_1^* = p_2^* + \frac{c(L-a-b)}{2}$, and revenue maximization in D_{22} implies $p_2^* = p_1^* + \frac{c(L-a-b)}{2}$; these two implications are clearly impossible together if $L - b \neq a$, as assumed. Similarly, no price equilibrium can occur with $p_1^* \in D_{11}$ and $p_2^* \in D_{22}$ (or the symmetric case, $p_1^* \in D_{12}$ and $p_2^* \in D_{21}$) : when $p_2^* \in D_{22}$, it must be equal to $p_1^* + \frac{c(L-a-b)}{2}$, so that $p_2^* > p_1^*$, contradicting the fact that $p_1^* \in D_{11}$. Furthermore, an equilibrium (p_1^*, p_2^*) with $p_1^* \in D_{11}$ and $p_2^* \in D_{21}$, or $p_1^* \in D_{13}$ and $p_2^* \in D_{23}$, is also impossible for evident reasons. We must finally exclude the case where $p_1^* \in D_{13}$ and $p_2^* \in D_{22}$ (or the symmetric case : $p_1^* \in D_{12}$ and $p_2^* \in D_{23}$). In that case it must be that $p_2^* = p_1^* + \frac{c(L-a-b)}{2}$, so that $p_1^* = p_2^* - \frac{c(L-a-b)}{2}$ $\notin D_{13}$, a contradiction. Consequently we are left with the only possibilities : (i) $p_1^* \in D_{13}$ and , simultaneously, $p_2^* \in D_{21}$, and/or (ii) $p_1^* \in D_{11}$ and, simultaneously, $p_2^* \in D_{23}$.

In case (i), since the pair (p_1^*, p_2^*) is assumed to be a price equilibrium, the prices p_1^* and p_2^* must (in particular) solve simultaneously

$$\underset{p_1 \in D_{13}}{\text{Max}} \left(\frac{p_2^* - p_1 + ac}{c}\right) \cdot p_1$$

and

$$\underset{p_2 \in D_{21}}{\text{Max}} \left(L - \frac{p_2 - p_1^* + ac}{c} \right) \cdot p_2 \, .$$

Since D_{13} and D_{21} are both semi-open intervals, the pair (p_1^*, p_2^*) can be an equilibrium only if they are interior to D_{13} and D_{21} , respectively. Accordingly, first-order conditions must be satisfied, which imply that $p_1^* = \frac{c}{3}(L + a)$ and $p_2^* = \frac{c(2L - a)}{3}$ (equilibrium of type I). In case (ii), the prices p_1^* and p_2^* must (in particular) solve simultaneously

$$\underset{p_1 \in D_{11}}{\text{Max}} \left(\frac{p_2^* - p_1 + c(L - b)}{c} \right) \cdot p_1$$

and

$$\underset{p_2 \in D_{23}}{\text{Max}} \left(L - \frac{p_2 - p_1^* + c(L - b)}{c} \right) \cdot p_2 \, .$$

Since D_{11} and D_{23} are both semi-open intervals, the pair (p_1^*, p_2^*) can be an equilibrium only if they are interior to D_{11} and D_{23} , respectively. Accordingly, first-order conditions must be satisfied, which imply that $p_1^* = \frac{c}{3}(L + b)$ and $p_2^* = \frac{c(2L - b)}{3}$ (equilibrium of type II).

Q.E.D

We notice that an equilibrium of type II is simply an equilibrium of type I where a has been replaced by b . In the following we study equilibria of type I, but everything which is said or proved about these equilibria,finds its counterpart for equilibria of type II by permuting the parameters a and b . For each of the following propositions (which characterize an equilibrium of type I), we shall provide in parenthesis their counterpart for an equilibrium of type II, dispensing with proofs.

Before studying the conditions under which the pair of prices $(p_1^*, p_2^*) = \left(\frac{c(L + a)}{3}, \frac{c(2L - a)}{3} \right)$ is an equilibrium of type I, we need the following

<u>*LEMMA 1*</u>. *Let* $p_2^* = \frac{c(2L - a)}{3}$ *and assume* $a < \frac{L}{2}$ *; then, either*

$$\forall p_1, \; R_1 \left(\frac{c}{3}(L + a), \, p_2^* \right) \geq R_1(p_1, p_2^*) \, ,$$

or

$$\forall p_1, \; R_1 \left(p_2^* + \frac{c(L - a - b)}{2}, \, p_2^* \right) \geq R_1(p_1, p_2^*) \, .$$

<u>*LEMMA 2*</u>. *Let* $p_1^* = \frac{c(L+a)}{3}$ *and assume* $a < \frac{L}{2}$ *; then either*

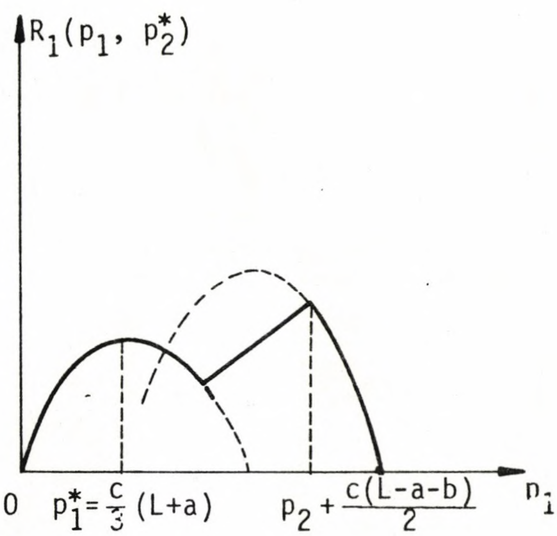
$$\forall p_2,\ R_2\left(p_1^*, \frac{c(2L-a)}{2}\right) \geqslant R_2(p_1^*, p_2)\ ,$$

or

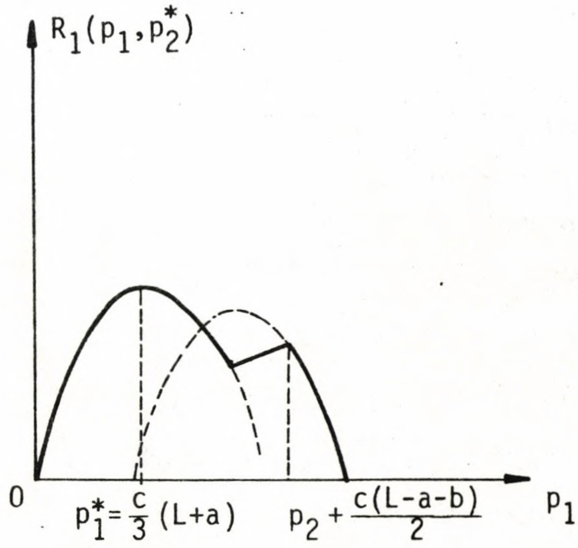
$$\forall p_2,\ R_2\left(p_1^*, p_1^* + \frac{c(L-a-b)}{2}\right) \geqslant R_2(p_1^*, p_2)\ .$$

(the proofs of the lemmas are given in appendix).

Lemma 1 states that, if $a < \frac{L}{2}$, and if firm 2 plays the strategy $p_2^* = \frac{c(2L-a)}{3}$ which is the best reply for player 2 in D_{21} against $p_1^* = \frac{c}{3}(L+a)$ (see proposition 1), the only strategy of firm 1 which can eventually beat p_1^* is the best reply in D_{12} against p_2, i.e. $p_2^* + \frac{c(L-a-b)}{2}$ The two alternative profiles for $R_1(p_1, p_2^*)$ are depicted in Figures 5.1 and 5.2.



<u>Figure 5.1</u>



<u>Figure 5.2</u>

Lemma 2 states that, if $a < \frac{L}{2}$, and if firm 1 plays the strategy $p_1^* = \frac{c(L+a)}{3}$, which is the best reply for player 1 in D_{13} against $p_2^* = \frac{c(2L-a)}{3}$ (see proposition 1), the only strategy of firm 2 which can eventually beat p_2^* is the best reply in D_{22} against p_1^*, i.e. $p_1^* + \frac{c(L-a-b)}{2}$. The two alternative profiles for $R_2(p_1^*, p_2)$ are depicted on Figures 6.1 and 6.2.

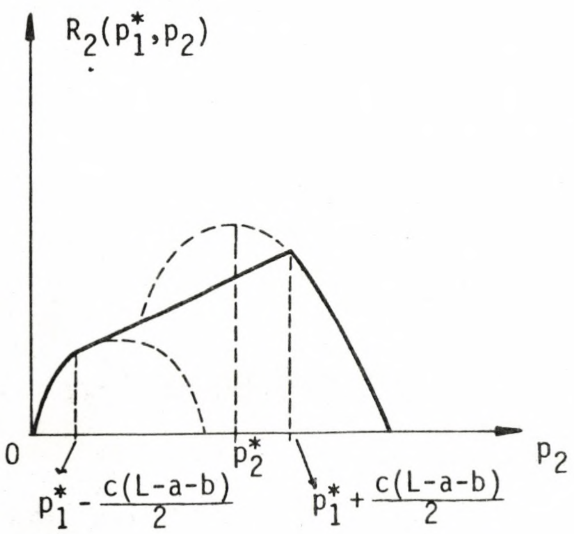


Figure 6.1

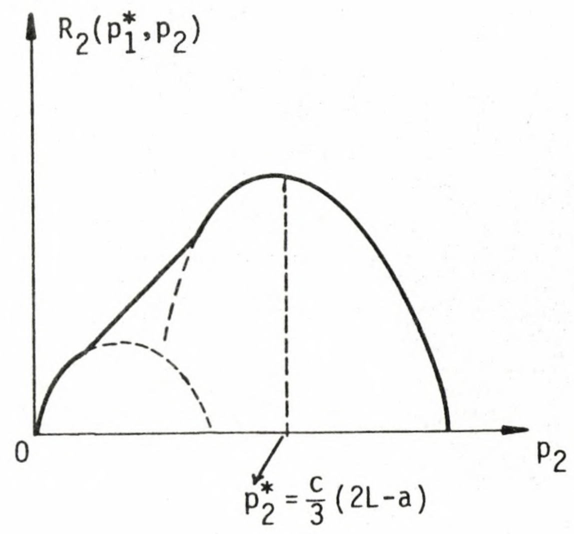


Figure 6.2

We are now in a position to establish that the pair of prices $(p_1^*, p_2^*) = \left(\frac{c(L+a)}{3}, \frac{c(2L-a)}{3}\right)$ is, indeed, a price equilibrium when some conditions on the location parameters are satisfied. To get an intuition on the nature of these conditions, we notice that for obtaining an equilibrium of type I, it is needed that the graph $R_1(p_1, p_2^*)$ is as on figure 5.2 and, *simultaneously*, the graph of $R_2(p_1^*, p_2)$ is as on figure 6.2. Otherwise at least one of the firms can yield a higher revenue by deviating from (p_1^*, p_2^*).

PROPOSITION 2. (Existence)

If $a < \frac{L}{2}$ *, there always exists a nonnull set of* b*-values for which an equilibrium of type I exists at the corresponding pair of locations* (a,b).

(If $b < \frac{L}{2}$ *, there always exists a nonnull set of* a*-values for which an equilibrium of type II exists at the corresponding pair of locations* (a,b)*).*

Proof : By definition, an equilibrium of type I is the pair of prices $(p_1^*, p_2^*) = \left(\frac{c}{3}(L+a), \frac{c}{3}(2L-a)\right)$. By lemma 1, if $a < \frac{L}{2}$ and if $R_1(p_1^*, p_2^*) \geqslant R_1\left(p_2^* + \frac{c(L-a-b)}{2}, p_2^*\right)$, then $R_1(p_1^*, p_2^*) \geqslant R_1(p_1, p_2^*)$ for all p_1. Similarly, by lemma 2, if $a < \frac{L}{2}$ and if $R_2(p_1^*, p_2^*) \geqslant R_2(p_1^*, p_1^* + \frac{c(L-a-b)}{2}$, then $R_2(p_1^*, p_2^*) \geqslant R_2(p_1^*, p_2)$ for all p_2. Thus we are left with the problem of proving that, for each $a < \frac{L}{2}$, there is a nonnull set of b-values for which

$$R_1(p_1^*, p_2^*) \geq R_1\left(p_2^* + \frac{c(L-a-b)}{2}, p_2^*\right) \quad (1)$$

and

$$R_2(p_1^*, p_2^*) \geq R_2\left(p_1^*, p_1^* + \frac{c(L-a-b)}{2}\right). \quad (2)$$

It follows from lemma 3 that given the location a, the set of b-values verifying inequality (1) obtains as

$$B(a) = \left\{b \mid 0 \leq L-a-b \leq -\frac{2}{3}(a+L) + \frac{2}{3}\sqrt{(a+L)^2+(L-2a)^2} \underset{\text{Def}}{=} \varepsilon^*\right\}.$$

Let us show that for any pair (a,b) with $b \in B(a)$, inequality (2) must also hold. First notice that $b \in B(a) \Rightarrow \frac{L+a}{3} \leq b$, since $b \in B(a) \Rightarrow L-a-b \leq \varepsilon^* <$ $< \frac{2}{3}(L-2a)$, where the last inequality follows from direct computation using $a < \frac{L}{2}$. Furthermore direct computation also shows that

$$p_2^* = \frac{c}{3}(2L-a) \geq p_1^* + \frac{c(L-a-b)}{2} = \frac{c}{3}(L+a) + \frac{c(L-a-b)}{2}$$

$$\Longleftrightarrow \frac{L+a}{3} \leq b \quad \text{and} \quad a < \frac{L}{2}.$$

Consequently, $b \in B(a) \Rightarrow p_2^* \geq p_1^* + \frac{c(L-a-b)}{3}$. In turn, the last inequality implies inequality (2) : given the continuity of $R_2(p_1^*, p_2)$ and the fact that $R_2(p_1^*, p_2^*) \geq R_2(p_1^*, p_2)$ for all $p_2 \in D_{21}$, it must also be that $R_2(p_1^*, p_2^*) \geq$ $R_2\left(p_1^*, p_1^* + \frac{c(L-a-b)}{2}\right)$, since $p_1^* + \frac{c(L-a-b)}{2}$ is in the closure of D_{21}.

In conclusion, for each location $a < \frac{L}{2}$, and all $b \in B(a)$, - a non null set - , both inequalities (1) and (2) are satisfied, which completes the proof of proposition 2.

Q.E.D.

PROPOSITION 3. (No Symmetric Equilibrium)

No price equilibrium of type I exists if $b \leq a$ *(No equilibrium of type II exists if* $a \leq b$ *).*

Proof : First assume $a = b$. Then, by proposition 2, an equilibrium of type I exists at the pair (a,a) if, and only if, $a \in B(a)$ or, equivalently, iff $\varepsilon(a) = L-2a < \varepsilon^*$, where $B(a)$ and ε^* are defined as in the proof of proposition 2. However, the direct comparison of $L-2a$ and ε^* shows that $\varepsilon^* < L-2a$ whenever $a < \frac{L}{2}$, an inequality which must hold if $a = b$. Consequently no equilibrium of type I exists when $a = b$. Ib $b < a$, then $\varepsilon = L - a - b >$ $L - 2a \Rightarrow L - a - b > \varepsilon^*$, so that b cannot belong to $B(a)$.

Q.E.D

PROPOSITION 4. (Unicity)

Whenever a price equilibrium exists, it is unique.

Proof : Given a pair (a,b) we know from proposition 1 that there can be at most two price equilibria. But there cannot be a pair (a,b) for which both an equilibrium of type I and an equilibrium of type II exist simultaneously. Indeed, from proposition 3, no equilibrium exists if $a = b$ and, if $a < b$, no equilibrium of type II exists while if $b < a$, no equilibrium of type I exists.

Q.E.D.

Until now we have analyzed the properties of price equilibria at given locations of the sellers. Whenever the firms are also allowed to choose their locations in addition to price, the link between the former and the latter choice is traditionally analyzed as a sequential game where first locations, and then prices are chosen. In this sequence both merchants can anticipate, when they choose their location, the consequences of their choice on price competition. Consider that seller 1 is allowed to choose his location a, given location b, in the range of a-values where an equilibrium of type I exists. Substituting equilibrium prices (p_1^*, p_2^*) is his revenue function yields, as a function of a only,

$$R_1(a) = \frac{c(L+a)^2}{9} \quad ,$$

which increases monotonically with a. On this fact rests

PROPOSITION 5. (Clustering)

Given the location b *of seller 2,*

$$\frac{dR_1(p_1^*(a,b),\ p_2^*(a,b))}{da} > 0 \quad ,$$

in the set $\{a|$ *there exists a type I equilibrium at* $(a,b)\}$, *where* $p_1^*(a,b)$ *and* $p_2^*(a,b)$ *denote the values of equilibrium prices at locations* (a,b).

Proposition 5 states that, if the effects of choice location on price competition is taken into account, there is a clear incentive for seller 1 to cluster together with seller 2 (a proposition similar to proposition 5 holds for seller 2, in the range of b-values for which an equilibrium of type II exists, given the location a of seller 1).

4. SUMMARY

In this paper we have considered a situation where the collect of information by consumers creates an externality on the transaction costs required for buying a commodity : information comes out as a byproduct of canvassing the first shop. On the other hand each firm has initially a "natural" market : to the extent that buyers incur transaction costs proportional to the distance to the firm, all consumers closer to a particular firm first call that firm. The combined effects of these two features lead to a market equilibrium in which prices are *necessarily* dispersed.

Furthermore a market equilibrium can exist only if there is a significant asymmetry in the size of the "natural" market of each firm. This asymmetry requires that firms are not located too far apart from each other. Then, the seller enjoying the larger natural market cannot benefit, at an equilibrium, from undercutting his rival's price; should he do so, the revenue increase due to a larger market share cannot be sufficient to compensate him for the loss due to a lower per unit price than at equilibrium. At the same time the seller with the smaller natural market prefers to capture part of his rival's clientele through a low enough price, rather than satisfy the demand of his own "natural" customers at a higher per unit price than at equilibrium. This fact, in turn, generates an incentive for the "smaller" firm to cluster with the other, reducing thereby the portion of the market which lies between the two firms.

In conclusion, it may be of interest to note that the manner by which the two sellers compete and the nature of a price equilibrium are markedly different from what Hotelling described in his original work ([7]), where he assumed consumers to be perfectly informed. In that case, indeed, for a price equilibrium to exist, it is required that firms lie far apart from each other, otherwise price competition does not stabilize (see [3]).

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APPENDIX

LEMMA 1.

Let $p_2^* = \frac{c(2L-a)}{3}$ *and assume* $a < \frac{L}{2}$ *; then either*

$$\forall p_1 \ , \ R_1\left(\frac{c}{3}(L+a),\ p_2^*\right) \geq R_1(p_1,\ p_2^*) \ ,$$

or

$$\forall p_1 \ , \ R_1\left(p_2^* + \frac{c(L-a-b)}{2}\ ,\ p_2^*\right) \geq R_1(p_1,\ p_2^*\ ) \ .$$

Proof : In any case if a price $\tilde{p}_1$ verifies the property :

$$\forall p_1,\ R_1(\tilde{p}_1,\ p_2^*) \geq R_1(p_1,\ p_2^*) \ ,$$

it must be that $\tilde{p}_1$ is solution of either

$$\max_{p_1 \in D_{13}} \left(\frac{p_2^* - p_1 + ac}{c}\right) p_1 \tag{1}$$

or

$$\max_{p_1 \in D_{11}} \left(\frac{p_2^* - p_1 + c(L-b)}{c}\right) p_1 \tag{2}$$

or

$$\max_{p_2 \in D_{12}} \left(\frac{L+a-b}{2}\right) p_1 \ , \tag{3}$$

where D_{11} , D_{12} and D_{13} are defined as in Proposition 1. Let us show that, if $a < \frac{L}{2}$, the solution $\tilde{p}_1$ to problem (3) must lead to a revenue $R_1(\tilde{p}_1,\ p_2^*)$ which exceeds $R_1(p_1,\ p_2^*)$ for all p_1 in D_{11} , leaving us with either case (1) or (3). First it is clear that $\tilde{p}_1$ solution to problem (3) is equal to $p_2^* + \frac{c(L-a-b)}{2}$, that is ,

$$\tilde{p}_1 = \frac{c(4L-5a-3b)}{6} \ .$$

On the other hand the solution p_1' , say, to problem 2 is easily derived as

$$p_1' = \frac{c(5L-a-3b)}{6} \ .$$

Since the inequality $a < \frac{L}{2}$ implies that $p_1' < \tilde{p}_1$, the concavity of $R_1(p_1, p_2^*)$ in the domain D_{11} insures that $R_1(p_1, p_2^*) \leq R_1\left(p_2^* + \frac{c(L-a-b)}{2}, p_2^*\right)$ for all $p_1 \in D_{11}$. On the other hand, and easy calculation shows that $p_1 = \frac{c}{3}(L+a)$ is solution to problem (1) for $a < \frac{L}{2}$, which completes the proof of lemma 1.

Q.E.D

LEMMA 2.

Let $p_1^* = \frac{c(L+a)}{3}$ *and assume* $a < \frac{L}{2}$, *then either :*

$$\forall p_2, \quad R_2\left(p_1^*, \frac{c(2L-a)}{3}\right) \geq R_2(p_1^*, p_2)$$

or

$$\forall p_2, \quad R_2\left(p_1^*, p_1^* + \frac{c(L-a-b)}{2}\right) \geq R_2(p_1^*, p_2) .$$

Proof : In any case if a price $\tilde{p}_2$ verifies the property

$$\forall p_2, \quad R_2(p_1^*, \tilde{p}_2) \geq R_2(p_1^*, p_2)$$

it must be that $\tilde{p}_2$ is solution of either

$$\underset{p_2 \in D_{23}}{\text{Max}} \left(L - \frac{p_2 - p_1^* + c(L-b)}{c} \right) p_2 , \tag{1}$$

or

$$\underset{p_2 \in D_{21}}{\text{Max}} \left(L - \frac{p_2 - p_1^* + ac}{c} \right) p_2 , \tag{2}$$

or

$$\underset{p_2 \in D_{22}}{\text{Max}} \left(\frac{L-a+b}{2} \right) p_2 , \tag{3}$$

where D_{21}, D_{22} and D_{23} are defined as in proposition 1. Let us show that, if $a < \frac{L}{2}$, the solution p_2 to problem (3) must lead to a revenue $R_2(p_1^*, \tilde{p}_2)$ which exceeds $R_2(p_1^*, p_2)$ for all $p_2 \in D_{23}$, leaving us with case (2) or (3). First it is clear that $\tilde{p}_2$, solution to problem (3) is equal to $p_1^* + \frac{c(L-a-b)}{2}$, so that we have necessarily that $R_2\left(p_1^*, p_1^* + \frac{c(L-a-b)}{2}\right) \geq R_2\left(p_1^*, p_1^* - \frac{c(L-a-b)}{2}\right)$
It is therefore sufficient to show that $R_2\left(p_1^*, p_1^* - \frac{c(L-a-b)}{2}\right) \geq R_2(p_1^*, p_2)$ for all $p_2 \in D_{23}$. Since $R_2(p_1^*, p_2)$ is concave in the domain D_{23}, the last

inequality must hold if the unconstrained solution $\tilde{p}_2$ to problem (1) exceeds $p_1^* - \frac{c(L-a-b)}{2}$. An easy calculation shows that $\tilde{p}_2 = \frac{c(L+a+3b)}{6}$, which exceeds $p_1^* - \frac{c(L-a-b)}{2}$ if $a < \frac{L}{2}$. On the other hand, it is clear that $p_2 = \frac{c}{3}(2L-a)$ is solution to problem (2), when $a < \frac{L}{2}$, which completes the proof of lemma 2.

Q.E.D

LEMMA 3.

Given the location a, $a < \frac{L}{2}$, *the set of* b*-values verifying*

$$R_1(p_1^*, p_2^*) \geqslant R_1\left(p_2^* + \frac{c(L-a-b)}{2}, p_2^*\right) \qquad (4)$$

is equal to

$$B(a) = \left\{b \mid 0 \leqslant L-a-b \leqslant \frac{2}{3}(a+L) + \frac{2}{3}\sqrt{(a+L)^2+(L-2a)^2} \underset{\text{Def}}{=} \varepsilon^*\right\}.$$

Proof : Substituting in $R_1(p_1, p_2)$ for the values p_1^*, p_2^* and $p_2^* + \frac{c(L-a-b)}{2}$, (4) can be rewritten as

$$\frac{c(L+a)^2}{9} \geqslant \left[\frac{c(7L-5a-3b)}{6}\right] \cdot \left(\frac{L+a-b}{2}\right) .$$

Define ε by $\varepsilon = L-a-b$ and $D(\varepsilon)$ by $D(\varepsilon) = (6a+3\varepsilon)(4L-2a+3\varepsilon) - 4(L+a)^2$: the inequality (4) holds iff, at the pair (a,b), $D(\varepsilon) \leqslant 0$. Rewriting $D(\varepsilon)$ as

$$D(\varepsilon) = 9\varepsilon^2 + 12\,\varepsilon(a+L) - 4(L-2a)^2 ,$$

we notice that $D(\varepsilon) < 0$ if $\varepsilon = 0$ and $\frac{dD}{d\varepsilon} > 0$ if $\varepsilon > 0$, an inequality which must hold since $L-b > a$. Furthermore $\frac{d^2D}{d\varepsilon^2} > 0$ and

$$D(\varepsilon) = 0 \iff \varepsilon = -\frac{2}{3}(a+L) \pm \frac{2}{3}\sqrt{(a+L)^2+(L-2a)^2} .$$

Since ε must be greater than 0, we have only to consider the positive root

$$\varepsilon^* = -\frac{2}{3}(A+L) + \frac{2}{3}\sqrt{(a+L)^2+(L-2a)^2} > 0 ,$$

if $a < \frac{L}{2}$. (The graph of $D(\varepsilon)$ is depicted on Figure 7). Accordingly, given the location a, the set of b-values verifying

$$R_1(p_1^*, p_2^*) \geqslant R_1\left(p_2^* + \frac{c(L-a-b)}{2}, p_2^*\right)$$

is given by $B(a) = \{b \mid 0 \leqslant L-a-b \leqslant \varepsilon^*\}$

Q.E.D

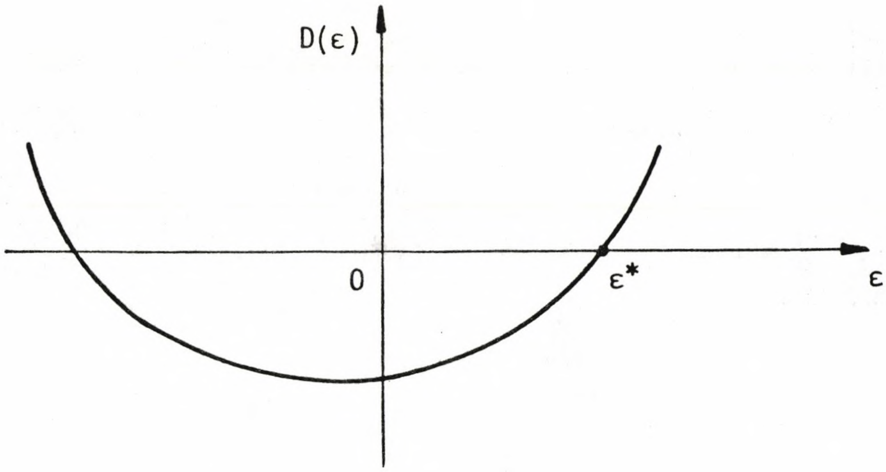

Figure 7.

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